TITLE PAGE

Title

The environmental impact of community caries prevention. Part 3: water fluoridation.

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ABSTRACT

Introduction. Community-level interventions for the prevention of dental caries in children include fluoride varnish in schools, supervised toothbrushing in schools, the provision of toothbrushes and toothpaste, and water fluoridation. The environmental impact of these interventions is an important factor to consider when commissioning these services.

Materials and methods. A comparative life cycle assessment (LCA) was conducted to quantify the environmental impact of fluoridation of the public water supply for a 5-year-old child over a one-year period. These results were compared to LCA data for fluoride varnish in schools, supervised toothbrushing, and the provision of toothbrushes and toothpaste.

Results. When comparing community level caries prevention programmes, water fluoridation had the lowest environmental impact in all 16 categories, and had the lowest disability adjusted life years (DALY) impact.

Discussion. All community-level caries prevention programmes have an associated environmental cost. Water fluoridation performed well in this LCA study in all measures of environmental sustainability. The results of this study could be used, along with cost and clinical effectives data, to inform public healthcare policy.

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INTRODUCTION

The climate emergency is real and action needs to be taken now. As outlined in the first paper of this series, healthcare has a role to play, with prevention of disease being key. In the first 2 papers, we outlined the problem and what this means for dentistry. We described the sustainability of community-based fluoride varnish and toothbrushing programmes. These were selected because they are recommended by Public Health England, and because they are well evidenced therapies.[1]

In this final paper, we will consider water fluoridation. Water fluoridation is regarded as one of the most significant public health interventions of the 20th century.[2] Today, over 35% of the world's population have access to water fluoridation with studies showing significant reductions in dental caries.[3]

Whilst data on the clinical effectiveness, and cost analysis of water fluoridation are available, there is no data regarding its environmental impact. This paper has 2 aims:

1. To quantify the environmental impact of water fluoridation for an individual 5-year-old child over a 1-year period.
2. To compare this environmental impact with use of fluoride varnish and toothbrushing programmes.

MATERIALS AND METHODS

This study used life cycle assessment (LCA) methodology to quantify the environmental impact of water fluoridation. The primary outcome measure was the life cycle impact assessment (LCIA), and secondary outcome measures included normalised results, contribution analysis, and disability adjust life years (DALYs). These outcomes were then compared to other community-level caries prevention programmes; fluoride varnish in schools, supervised toothbrushing in schools, and the provision of toothbrushes and toothpaste.

The LCA was undertaken at Dublin Dental University Hospital (Trinity College Dublin) in partnership with the UCL Eastman Dental Institute, London. To allow comparison with the other papers in this series, the functional unit was defined as a 5-year-old child receiving water fluoridation over a 1-year period. The process of public water fluoridation in Ireland was used to create the model. The system boundaries are shown in Figure 1.

Assumptions and exclusions

A life cycle inventory was created for water fluoridation. Irish Water was consulted about the process of water fluoridation in Ireland. This process fluoridated the water supply at an average of 0.7mg/L.

Commented [GU2]: Just to clarify, who was this representative?

The water supply in Ireland was fluoridated using hexafluorosilicic acid (HFSA), which was manufactured in Bilbao, Spain. HFSA is produced through two chemical reactions. Firstly, fluorspar and sulphuric acid were combined to form hydrogen fluoride, with calcium sulphate formed as a by-product. Secondly, the hydrogen fluoride was mixed with silica quartz to form hexafluorosilicic acid. The energy required for these reactions was based on the energy use ((kilowatt (kW) of the machinery used and the heat needed for both endothermic reactions (based on the difference between bond strengths). The production and maintenance of the manufacturing machinery was excluded from the system boundaries.

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Commented [GU4]: 'by-product' rather than 'biproduct'?

The calcium sulphate, a by-product of the HFSA production, was combined with water to form gypsum. Gypsum was not used in the water fluoridation process, but is reused in the life cycle of other products such as fertilisers and cements, and keeping with appropriate LCA methodology was modelled as an environmental output.

HFSA was diluted in water to 40%. This liquid product was then transported to Ireland. The transport was assumed as lorry from the Bilbao factory to Bilbao port, then shipped from Bilbao to Shannon, Ireland. In Shannon, the 40% HFSA was diluted further with water to 10.9%. From this central water plant, the 10.9% HFSA was transported via lorry to each local water plant, assumed in this model to be the population centre of Ireland. The distances were estimated in km using GoogleMaps (2021).

At the local water plant, the HFSA was combined into the main water supply via 3 pumps, incorporating the fluoridated water into the mainline water supply. The energy required for this process was estimated in kilowatt hours (kWh). The additional volume of water needed in the production of HFSA was disposed of as waste tap water.

The allocation of resources for an individual person for 1-year was based on 3.76 million litres of HFSA (at 10.9% concentration) being used for water fluoridation in Ireland in the year 2020. This volume of HFSA was assumed to fluoridate the water supply for 69% of the total population of Ireland.[4,5]

Commented [GU5]: This is incorrect: 3.76million litres is total annual quantity of HFSA at 10.9% concentration delivered to water treatment plants in Ireland. The quantity of imported HFSA (at 40% concentration) would therefore be approx 1 million litres per annum

Data collection and analysis

LCA methodology was applied in line with ISO standards and European Union Product Environmental Footprint (PEF) guidance.[6,7] 16 separate impact categories were examined in this study, and the life cycle impact assessment methods were based on PEF guidance and are described in Table 1. The software OpenLCA v1.11 was used alongside the reference database Ecoinvent v3.7.1 for the life cycle impact assessment (LCIA) and ReCiPe (2016) Endpoint (H) was used to calculate disability adjusted life years (DALYs). The LCIA results were normalised against per capita reference values. In order to understand the impact of each programme alongside its environmental impact, the return-on-investment measures from PHE were mapped against the environmental impacts.[8]

RESULTS

The inventory table is available as online supplementary material. The results of the life cycle impact assessment (LCIA) are shown in Table 2.

The LCIA results were normalised against average global reference values for the annual environmental footprint of the average person, as shown in Figure 2. Following PEF recommendations, the three toxicity-related categories have been excluded while the robustness of the methodology is under review.[7] Fluoridating the water supply for an individual used the equivalent of approximately 0.01% of an average person's annual mineral and metal resource use, and 0.0057% of the average person's annual climate change impact.

Figure 3 shows the contribution analysis for each impact category. The land transport was the greatest contributor overall, accounting for an average of 48.21% of the impact (range between 8.24% - 82.57%), followed by the sulphuric acid needed to produce HFSA (average of 23.7%). The gypsum that is produced as a by-product resulted in a 'saving' as it is used in other product systems. This 'saving' reduced the overall contribution by 0.03-1.13%.

Commented [GU6]: 'by-product'

Table 3 shows the DALY calculations. Fluoridating the water supply for 1 child for 1 year contributes the equivalent of 20 seconds of disability adjusted life. Global warming was the biggest contributor, accounting for 65% of the overall DALY impact.

The results from this study were combined with LCA results from parts 1 and 2 in this series in order to compare the impact to fluoride varnish in schools, supervised toothbrushing, and the provision of toothbrushes and toothpaste (the provision of toothbrushes and toothpaste scenario included the tap water use for twice daily toothbrushing at home). Figures 4 and 5 compare the normalised results and DALY impact of these four prevention programmes.

DISCUSSION

This was the first study to quantify the environmental impact of water fluoridation per person. Water fluoridation had the lowest environmental impact of all the community level caries prevention programmes including in this series.

Like papers 1 and 2 in this series, there are a number of limitations with life cycle assessments. The actual energy required to produce HFSA was based on chemical equations using mol ratios; this method does not account for any waste in the factory processes. The Republic of Ireland processes for water fluoridation were used for the basis of the LCA model, whereas other countries could have different processes, in particular the main contributors such as transport within the country. Currently, 69% of Ireland's population have fluoridated water, primarily in denser population centres.[4] Actual environmental costs might differ should the infrastructure in Ireland be expanded to provide 100% of coverage. Similarly, the actual environmental costs in the UK or elsewhere could be different depending on the logistics of the process of fluoridation, for example the location of water treatment plants, transportation of HFSA to the plants, and population density.

In this final paper we have an opportunity to compare all the preventive interventions studied across this series. In table 4 we have shown the triple bottom line – effectiveness/cost/sustainability. We have used DALYs in order to facilitate comparison, as with the previous two papers care must be taken when interpreting these. For Water fluoridation, the DALYS are small with most of the impact coming from the personal health harm associated from global warming, and around one third coming from water consumption. There is a significant difference between the DALY impact (20 seconds) and environmental impact of water fluoridation compared with the other programmes. This difference in favour of water fluoridation is continued when looking at cost and effectiveness. We know that the cost of water fluoridation is low, at around €1.50 per person.[9] We also know that the intervention is historically one of the most successful public health interventions, with a reduction in caries of around 35% in primary teeth and 26% for permanent teeth.[3] The low (positive) environmental cost of water fluoridation mirrors the high (positive) return of investment cost.

Commented [GU7]: 'associated with'?

The greatest overall contributor to the environmental impact of water fluoridation was transporting the diluted HFSA within Ireland. Transport has been a recurrent theme through this series, and this highlights the importance of broader changes to transport and logistics in order to meet the climate challenge. For example, infrastructure and incentives for greener forms of transport, including electric vehicles and public transport.

Commented [GU8]: inserted 'a'

Water fluoridation is praised by most public health specialists as one of the best public health interventions of the 20th century.[2] However, its introduction and continued use is not without controversy. The debate around water fluoridation being harmful for the environment has continued since its inception; internet searches on google for "water fluoridation bad for the environment" produces 7.46 million hits.[10] Water fluoridation has been deemed safe by a number of different government bodies and provides significantly more benefit than any potential harm.[3] This paper adds further positive data around water fluoridation by emphasising its comparatively low environmental footprint compared to other established preventive programmes.

CONCLUSION

Our combined results between all three parts of this paper show that water fluoridation is most sustainable method of community level caries prevention, and PHE have also found gives greatest return on investment. Considering the balance between clinical effectiveness, cost effectiveness, and environmental sustainability, water fluoridation should be the preventive intervention of choice.

CONFLICT OF INTEREST

This study was funded by the Eastman Dental Institute (University College London). The authors declare no conflict of interest.

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AUTHOR CONTRIBUTIONS

BD lead the data collection and analysis and drafted/revised the paper; AL contributed to data collection and analysis and drafted/revised the paper; RP contributed to data collection and revised the paper; PA drafted the manuscript and revised the paper.

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FIGURE LEGENDS

Figure 1. System boundaries for water fluoridation
Figure 2. Normalised results for water fluoridation
Figure 3. Contribution analysis for water fluoridation
Figure 4. Normalised impact results for community prevention programmes.
Figure 5. Disability adjusted life seconds for community caries prevention programmes.

TABLE LEGENDS

Table 1. Impact categories and LCIA methods.
Table 2. LCIA results for water fluoridation.
Table 3. DALYs for water fluoridation.
Table 4: The triple bottom line: Return of Investment (PHE figures) combined with two measures of environment footprint (Carbon footprint and DALYs).